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Great Plains Irrigation, 1975-80

A Literature Review

Curtis A. Everson
Rodney L. Sharp

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GREAT PLAINS IRRIGATION, 1975-80: A LITERATURE REVIEW, by Curtis A. Everson and Rodney L. Sharp, Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Bibliographies and Literature of Agriculture No. 22.

ABSTRACT

This review of literature on irrigation in the Great Plains will acquaint researchers in irrigation with background information and references on: (1) distribution and pump selection, (2) management techniques and production costs for irrigated crops, (3) economics of irrigation with limited water, (4) impacts of and potential barriers to irrigation development, (5) energy use and conservation, (6) irrigation efficiency, (7) economics of irrigation with rising energy costs, (8) water quality, and (9) other literature.

KEYWORDS: Irrigation, Great Plains, Pump selection, Irrigation management, Irrigation development, Energy conservation, Water quality.

PREFACE

This review of literature contains Great Plains irrigation information published during the 1975-80 period. It is intended as a source of background information for researchers. It includes studies from a variety of disciplines. Because our scope is so large, we cannot claim to have included all works or to have given a complete analysis of each one. Nonetheless, we believe this review provides useful background information about irrigation in the Great Plains.

We would like to thank the following people for their assistance:

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Great Plains Irrigation, 1975-80

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INTRODUCTION

During the past decade, irrigation in the Great Plains region has expanded rapidly. The development of sprinkler irrigation technology in conjunction with the expansion of surface irrigation systems has brought much land into irrigated crop production. With the rapid development of irrigable lands, new problems have arisen that existing and prospective irrigators must face. Research and extension specialists from institutions throughout the Great Plains States have formulated many projects which focus on these problems. This literature review provides a body of reference materials that can be used as a basis for ongoing irrigation research.

In the early seventies, most publications dealt with investment in and operation of irrigation systems, system selection, management techniques, and crop production budgets. During the late seventies, attention was turned to the effects of energy shortages and, in some regions, to declining groundwater tables on irrigated agriculture. Much research was concerned with finding ways to conserve energy, such as increasing the pumping and application efficiencies of irrigation systems. Shortrun and longrun impacts of increasing energy costs were estimated. Increased pumping costs would certainly decrease the profitability of existing irrigation systems, but questions about their effects on future irrigation development remain.

Throughout the decade, attention was increasingly directed to the pollution of our Nation's lakes, streams, and underground aquifers. Effluent and sediment levels in irrigation return flows became a primary concern of environmentalists in the Great Plains. Legislation regulating allowable amounts of certain effluents was a direct result of research in this area.

Our literature review discusses and documents publications on irrigated agriculture written by research and extension

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personnel throughout the Great Plains. Vernon Eidman produced the first annotated bibliography of works related to Great Plains irrigation in 1967 and published a supplement the following year.^{1/} William Lagrone compiled the second supplement a year later,^{2/} and Gordon Sloggett produced the third supplement in 1976.^{3/}

The literature review is arranged by subjects, and within subjects, by State. A background discussion for each section describes research in the subject area. One should note that the background sections do not contain all of the references listed in the bibliography.

DISTRIBUTION SYSTEM AND PUMP SELECTION

Background

Research evaluating the advantages and disadvantages of many types of distribution systems can be useful when one is considering alternatives. Important factors in choosing an irrigation distribution system are soil types, topography, water supply, climate, crops, labor supply, economic feasibility, and finances. Several other factors must be considered in the selection of an irrigation pump--source of water, desired pumping rate, and total pumping head.

Sprinkler Systems

Sprinkler irrigation systems from which potential irrigators may choose include the following types: tow-line, side roll, big gun, lateral move, solid set, center pivot, and center pivot with corner attachment. An advantage of a properly designed sprinkler irrigation system is its ability to apply

1/ Vernon Eidman, An Annotated Bibliography of Publications Related to Great Plains Irrigation, Paper A.E. No. 6712, Oklahoma Agricultural Experiment Station, Stillwater, 1967; Paper A.E. No. 6809, Oklahoma Agricultural Experiment Station, Stillwater, 1968.

2/ William Lagrone, 1969 Supplement to An Annotated Bibliography of Publications Related to Great Plains Irrigation, Report No. 55, Nebraska Agricultural Experiment Station, Lincoln, Jan. 1970.

3/ Gordon Sloggett, Supplement No. 3, An Annotated Bibliography of Publications Related to Great Plains Irrigation, A.E. No. 7601, Economic Research Service, U.S. Department of Agriculture in cooperation with the Department of Agricultural Economics, Oklahoma State University, Stillwater, Mar. 1976.

water uniformly without runoff and erosion (32).^{4/} An improved procedure for sprinkler distribution testing was given by Hart and Heerman (2). Nozzle size and spacing vary depending on amount of pressure, root zone depth, infiltration rate, and water holding capacity of the soil. Addink determined the extent of water runoff under conventional rotating sprinklers for a center pivot system on two soil types (14) and considered the effect of spraying direction.

A circular prepared by Lundstrom compares four types of sprinkler systems: two line, side roll, big gun, center pivot, and center pivot with corner attachment (32). His analysis includes investment per acre and annual operating and ownership costs. He also discusses the adaptability of alternative systems to differently shaped fields. Frankenstein studied the adaptability of a hydraulic, variable, radii-center-pivot system to square, rectangular, or other noncircular areas (21). This study and others show that center pivots are adaptable to varying field shapes.

A relatively new concept in sprinklers is the development of low-pressure systems which reduce pumping costs. It is possible to convert most high-pressure, center-pivot systems to low-pressure ones. Schwab, Barefoot, and Jones report the correct procedure for converting the conventional self-propelled pivot systems (45). Other studies evaluate the effects of reducing water pressure on the performance of a center pivot (22, 33, 34).

Surface Systems

Alternative types of surface irrigation systems include ditch and siphon tube, level basin flood, border dike flood, gated pipe, and automated gated pipe systems. Major developments in gravity flow systems in recent years include tailwater reuse systems (61) and automated systems for pumping both surface water (8, 15) and groundwater (10, 20). Automated gated pipe is the most recent of these developments; the automated feature saves labor and has the potential for improving irrigation efficiency by reducing runoff and deep percolation.

Pump Selection

The types of pumps most commonly used for irrigation include centrifugal, deep well turbine, submersible, and propeller pumps. According to Lundstrom, centrifugal pumps can normally lift water 10-20 feet, deep well turbine pumps are best suited for wells, submersible pumps are used for wells with smaller horsepower motors, and propeller pumps are normally used in

^{4/} Underscored numerals in parentheses refer to items appearing in the bibliographical sections of this literature review.

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gravity irrigation because of their ability to deliver large amounts of water at low heads (31). However, one should recognize that each irrigation situation is unique and that pump selection must be based on individual needs.

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MANAGEMENT
TECHNIQUES AND
PRODUCTION COSTS
FOR IRRIGATED CROPS

Background

Today's irrigators must be expert in many fields. They must have a good working knowledge of agronomy, engineering, economics, and accounting. Extension specialists and researchers at universities and in governmental agencies attempt to provide irrigators with this information. The bibliography in this section consists primarily of publications dealing with management techniques and production costs for irrigated crops.

Production Costs

In most Great Plains States, agricultural economists work with irrigators to develop irrigated crop production budgets. Irrigators have been provided with average cost estimates to compare with their own costs. Irrigators can use these comparisons as a management tool to see whether they are incurring certain abnormally high costs. The following sources

MANAGEMENT TECHNIQUES AND PRODUCTION
COSTS FOR IRRIGATED CROPS

provide information on irrigated crop budgets:

Colorado (65, 66)	New Mexico (131-136)
Kansas (71, 72, 73, 74)	South Dakota (156, 157, 163)
Montana (93-106)	Texas (167)
Nebraska (111)	Wyoming (188-193)

Agronomists, engineers, and other specialists prepare and distribute valuable information to irrigators--as do agricultural economists. Agronomists provide technical information on nutrients necessary for healthy crop growth (92, 127, 129, 139, 143). Publications explaining or predicting the effects on specific crops of excessive levels of salinity or other chemicals in irrigation water are also available (67, 68, 69, 183).

Agricultural engineers supply irrigators with considerable technical data on the operation and maintenance of their irrigation systems. The adaptability of a specific type of irrigation system to a particular type of soil or crop is a crucial factor in the system selection process (130, 138, 143, 145, 147, 155, 180). Engineers also offer guidance on how to decrease pumping costs by increasing application efficiency of systems through irrigation scheduling (70, 78, 79, 142, 143, 148, 154, 180, 182, 195). The application of herbicides and fertilizers through irrigation systems is a relatively new activity which agricultural engineers and agronomists are now researching (108, 114, 116, 117, 118).

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ECONOMICS OF IRRIGATION WITH LIMITED WATER

Background

Throughout recorded history, human beings have employed irrigation techniques to increase the productivity of their land resources and reduce the uncertainty associated with crop production (198). Irrigation is critical for maintaining the level of crop production in many areas of the Great Plains. Limited irrigation water would have a significant impact on the region's economy (201). Most publications contained in this section of the literature review and evaluate water management techniques designed to maximize profitability with limited irrigation water.

Crop Response to Irrigation Scheduling

Irrigation scheduling is a function of the soil, crop, and atmosphere. For an effective scheduling program, the delivery and distribution systems must be adequate for the supply. Whenever water supply is insufficient for part of the growing season, a decision must be made about how to distribute the limited available water so as to achieve maximum profit (196).

Danielson, Langin, and Robinson have evaluated the amount and timing of irrigation on crop development, total consumptive water use, crop yield, and irrigation efficiency (199). This complex problem involves many variables, including plant growth throughout the season, soil moisture, and weather conditions that affect evapotranspiration (197).

A firm-level, bioeconomic simulation model was developed by Mapp and Eidman (227). Their model is capable of stochastically determining irrigated and dryland crop yields as a function of soil moisture and of atmospheric pressure during critical stages of plant growth. They evaluated three levels of groundwater management (no restriction, a quantity limitation, and a graduated tax per unit above the quantity limitation).

Stone, Gwin, and Dillon have evaluated the influence of irrigation timing on corn and grain sorghum (209). Variables consisted of no irrigation during the growing season, single irrigation at one of three selected growth stages, and irrigation at each of the three growth stages.

Groundwater Management

Groundwater management is the subject of many recent studies (212, 213, 214, 215, 232). Fisher points out alternatives in area management of groundwater (215). He maintains that

efficient and profitable irrigation on a continuing basis can be achieved if the average rates of withdrawal of water from groundwater aquifers are limited to the average rates of recharge prior to the exhaustion of water in storage. He argues that the essence of a practical system of water rights is to reserve to the public domain those rights required to provide for public needs and to protect the public interest. The primary objective of Baird's study is to measure public attitudes toward alternative public institutions with responsibility for groundwater planning and management (232).

Research to evaluate artificial and natural recharge and to detect groundwater supplies has also been conducted (203, 217). Longenbaugh has developed techniques for evaluating the area and distribution of natural recharge (200). He has defined procedures for estimating the quantity of water available for artificial recharge on the High Plains.

Using remote sensing techniques and color photographs taken within various spectral ranges by aircraft and satellite, Ryland, Schmer and Moore attempted to detect high water tables in irrigated agricultural lands (207).

Streamflow Variation Inadequate streamflow is common in areas where irrigation depends on varying streamflow. Anderson has examined the effects of streamflow variation on crop yields and incomes (196). During the peak runoff period, most water rights can be served. When the streamflow declines, farmers who have later water rights are denied water. Anderson concludes the greatest benefit from varying flow can be achieved only if streams are closely monitored so that all possible water rights can be served with original flow and with the return flow.

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IMPACTS OF AND
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TO IRRIGATION
DEVELOPMENT

Background

Irrigation development in the Great Plains has considerably affected the economies of counties and States within the region. It has increased agricultural production, has stimulated investment inside and outside the agricultural sector, and has created employment for many people. The effects on future development of high energy prices and of dwindling water supplies have also been studied.

Gray and McKean analyzed the relationship between water use in Colorado and the sectors of the State's economy (237). Research personnel in North Dakota have assessed the impacts of

the Garrison Diversion Project on the State's economy (245, 246).

Some economists have estimated the regional impacts of irrigation development. Axthelm and Splinter have enumerated some of the impacts of center pivot irrigation on the Texas High Plains economy (240). Thorson and Fisher (242) have studied the impact of irrigation development in the Sandhills of Nebraska, as have Carkner and Shaffner (243) for south central North Dakota. Brown and Shane have attempted to estimate the impact of potential irrigation development in a portion of South Dakota (255). Brown and Shane have found that potential nonfarm impacts of development are generally larger than direct farm impacts.

Possible barriers to further development have also been studied. Researchers in Oklahoma have become increasingly concerned over rising energy prices and their effects on pump irrigation in the Oklahoma Panhandle (251, 252, 253, 254). They are especially worried about the increasing price and the decreasing availability of natural gas as an irrigation fuel source. Lacewell and others are concerned with energy shortages and their potential impacts on the economy of the Texas High Plains (259).

Declining groundwater tables are affecting the amount of irrigation water being pumped in the Great Plains. Lacewell has also estimated the effects of declining water tables on the economy of the Texas High Plains. Casey, Jones, and Lacewell have used a regional linear programming model to estimate the adjustment of agricultural producers to declining groundwater levels in the High Plains of western Oklahoma and northern Texas (249); they showed some of the likely economic adjustments in terms of output, employment, and household income in the nonagricultural sectors.

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ENERGY USE AND CONSERVATION

Background

Energy used for pumped irrigation water accounts for over 20 percent of all energy used on U.S. farms (266, 293). Energy use has grown because of increased acreage and increased use of sprinkler systems which are more energy intensive than most surface systems. Greater energy use combined with substantial price increases has made energy conservation a major issue for pump irrigators. Therefore, improved system management is possibly the most important management tool for water and energy conservation available to irrigators.

Irrigation Scheduling

Irrigation scheduling is the most publicized management tool used by irrigators in the Great Plains region. Carefully planned water applications reduce water use and can significantly save energy. According to Gilley and Splinter, improved scheduling procedures for irrigation with sprinkler and gravity systems could reduce energy requirements by 50 percent (279). Properly timed water applications should be based on soil-water-plant relationships (267).

Effective irrigation management also requires water measurement, which in turn requires the effective use of a water meter (271). Robel, Thomas, and Hay give information on propeller meters, Pitot tubes, orifice plates, and the trajectory method for measuring water flow. Hill and Ruff have examined shunt-line metering systems for irrigation wells (262).

Energy can be conserved in irrigated agriculture in a variety of ways. Because of the increasing demands on energy and water resources, energy-water conservation practices in irrigated agriculture will also become more important.

Other Methods of Energy-Water Conservation

Whereas irrigation scheduling involves improving existing irrigation management practices, other energy-conserving measures involve changes in or additions to the systems themselves or in the crops being irrigated. Skold has examined some adjustments irrigators can make to combat rising energy costs (266). Adding tailwater reuse systems to existing surface irrigation systems or converting to an automated, gated pipe system are possible adjustments. Skold has also proposed growing crops which require less water.

Management can also cut costs by scheduling irrigations to control peak energy demands (283, 284, 286). Stetson and others maintain that, with proper management, peak summer electrical demand loads can be reduced without lowering crop yields (286).

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IRRIGATION EFFICIENCY

Background

Increasing irrigation efficiency is an important management tool for conserving energy and reducing irrigation costs. Because of escalating energy costs, maintaining high overall efficiency in irrigation is critical. Overall efficiency includes: (a) conveyance system efficiency, (b) pumping plant efficiency, and (c) distribution application efficiency.

Distribution System and Application Efficiency

One area for conserving energy is in application efficiency. Stone, Garton, and McCauley have examined two types of distribution systems, wide furrow and sprinkler, and have

evaluated the effect of different frequencies of application on yield (350). Deboer and others have also evaluated the effect on yield and water utilization (357). Their study focuses on center pivot and trickle irrigation systems.

Extensive research has been done on management techniques for improving application efficiency. Irrigation scheduling to match crop use patterns with water applications is a valuable management tool. Christensen and Westensen have discussed several factors critical to effective management of irrigation water (313). They maintain that to manage the application of water effectively, an irrigator must know the available water-holding capacity of the soil, the consumptive water use by crop, the amount and distribution of precipitation, and the efficiency of the irrigation system. Thomas has evaluated electrical resistance blocks as one method of measuring soil moisture for irrigation scheduling (311). Kroutil and Wilson have shown irrigators how to schedule irrigations using tensiometers in sandy soils (325). The costs of and guidelines for the proper use of the tensiometer are presented in a paper by Bauder and Lundstrom (339). Tensiometers have been evaluated as a tool for scheduling irrigation of grain sorghum by Shipley and Regier (369).

Jardine and Fox have compared commercial irrigation practices in sugar beets with irrigation scheduling based on monitoring soil moisture depletion (304). Management based on their results has made irrigation more efficient and has increased beet production. Gilley set up a computer supported scheduling program (322). Measuring crop evapotranspiration rate is another method for determining irrigation scheduling (305, 307, 308, 343, 344, 345, 349, 351, 358).

Minimizing deep percolation through the root zone is another important function of proper irrigation scheduling. Using a vacuum extractor buried below the root zone, Linderman, Miekle, and Schuman have measured deep percolation losses of water and nitrogen throughout the growing season (326). Determining the optimum crop water balance for selected crops at different growth stages and developing distribution systems to maintain that balance are the important factors in maximizing water use efficiency (363).

Pumping Plant Efficiency

Increasing the efficiency of irrigation pumping plants will conserve energy and reduce pumping costs. A study by Kramer and Hay proposes a method for estimating pumping plant efficiency and the number of years required to pay off an investment that increases pumping plant efficiency (309). Many publications demonstrate that the average efficiency of pumping plants is substantially below achievable standards. Trimmer

demonstrates from test results that nearly one-third of the energy used in Nebraska for pumping could be saved by adjusting all pumping plants to meet 100 percent of the Nebraska standard (332). A majority of these pumping plants could save enough in reduced energy costs to pay for their repair. Fischbach, Sulek, and Axthelm point out performance standards for deep-well pumping plants and show the benefits derived from pumping plan test data (321).

Another aspect of pumping plant efficiency is optimum well discharge. Helweg has published detailed criteria for obtaining the best discharge for a given well (303). He concludes that to maximize the net benefits of an operation, the pump must match the discharge capacity of the well. He maintains that previous groundwater criteria have ignored the economic aspects of this analysis.

Conveyance System Efficiency

A report by the U.S. Department of Interior, U.S. Department of Agriculture, and the Environmental Protection Agency points out that conveyance losses can be primarily attributed to: (a) permeable canals, (b) obsolete, inadequate, or improperly maintained facilities, and (c) excessive vegetative growth (377). Lining the canals is the chief method of increasing the efficiency of conveyance systems. According to the report, any improvement or changes acceptable from an economic, environmental, and social standpoint would require public financial assistance.

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ECONOMICS OF IRRIGATION WITH RISING ENERGY COSTS

Background

Among the many problems currently confronting irrigators across the Great Plains, rapidly rising energy costs is one of the most threatening. Irrigators who pump water from relatively deep wells or through systems requiring high operating pressure are especially sensitive to rising energy costs.

The impacts rising energy prices may have on irrigated agriculture are varied. A study by Erickson estimated when it will no longer be profitable to irrigate crops in a portion of southwest Nebraska (383). Mapp, Dobbins, and Eidman considered similar impacts in northwest Oklahoma (391).

If rising energy costs can cause some current irrigators to stop pumping, potential irrigators should evaluate the profitability of investing in a new irrigation system. Pretzer laid down guidelines for producers in deciding whether or not

ECONOMICS OF IRRIGATION WITH RISING ENERGY COSTS

irrigation would be a profitable addition to a cropping program (382).

Several management techniques which could lessen the adverse effects of rising energy prices are available. Numerous publications have examined the economic merits of increased irrigation pump and/or application efficiencies on irrigated crop enterprises (378, 379, 380, 397). Bogle has examined the ramifications of changing from crops that require large amounts of irrigation water to grain sorghum which uses less water (381). Researchers in Colorado have compared the profitability of center pivot irrigation to irrigation using gated pipe with a tailwater reuse system (378, 379). Their results generally favored the gated pipe system because of its lower pumping costs; however, minor changes in costs or yields could easily offset its advantages. Skold has also examined the possibility of substituting another production input, nitrogen, for water as well as the effect of decreasing the amount of water applied, holding other inputs constant (380).

The other publications referenced in this section examine alternative views of the plight of Great Plains irrigators who face rising energy costs. They also suggest how irrigators can best cope with declining profits.

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WATER QUALITY

Background

Irrigated lands provide excellent opportunities for increasing agricultural productivity because water can be managed to balance optimum use of other productive inputs (408). Information is needed on management practices that increase production while protecting the environment. Kruse has examined management techniques which increase crop production without causing environmental damage (408).

The buildup of salt in both water and soil is an environmental problem in some areas of the Great Plains. Research has been done on salinity control and on the effects of water and soil salinity on crop production (403, 409, 410, 411, 412, 420, 421, 424, 426, 427, 429) as well as on the buildup of other minerals and their effects (405, 406).

The runoff of excess irrigation water also concerns environmentalists throughout the Great Plains. Blackman, Wills, and Celnicker have pointed out the need to control pollutant discharges via irrigation return flows (401). Yet, a major cause of mineral buildups in irrigated soils is the increased use of irrigation return flow reuse systems in which the excess water that previously would have run out the end of a field is retained and pumped back over that field again.

Salinity Control

Many techniques can reduce salt pickup. Skogerboe and others have performed an input-output analysis using a hydro-salinity model (410). The key to reducing the salt load contribution of the Grand Valley to the Colorado River is in improving onfarm management practices so deep percolation losses and consequent salt pickup can be minimized.

Evans has evaluated a furrow irrigation system as an alternative to controlling salinity in irrigation return flows (402). He has developed a new semiautomatic gate for use in

two field systems. Initial field experience indicates good performance and has eliminated several previously reported gate design problems.

Lining irrigation canals can also be used to control salinity. Skogerboe and Walker have reported that lining the canals and laterals in a test area reduced the salt loads carried by the Colorado River by 4,700 tons (411). The indirect results of improved canal operations enhance the benefits of conveyance channel lining for salt management in areas of high potential salt pickup.

Effect of Saline Water on Crop Production

Moore and Hefner have modifications of current irrigation management systems that irrigate with saline water in the Pecos Valley of west Texas (426). For 30 years, this valley has been irrigated with saline groundwater, which has restricted crops to more salt-tolerant plant species and has required excessive water applications for leaching.

Thomas, Salines, and Oerther have studied methods of irrigating sugarcane with saline groundwater without reducing yields excessively or salinizing the root zone (429). Franklin and Hussan have investigated the effects of water and soil salinity on milo yields (404). Their results show that grain yields were depressed by salinity but that stover production was not.

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